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Associated H I in Absorbers at High Redshift

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Abstract. WSRT observations have provided a first inventory of the incidence of H I 21 cm line absorption associated with AGN at redshifts up to z=1.0. There is a large range in line depths, from $\tau = 0.44$ to $\tau \leq 0.001$, and a substantial variety of line profiles, from Gaussians of less than ten km s^{-1} to more typically a few hundred km s^{-1}, as well as irregular and multi-peaked absorption, sometimes spanning many hundreds of km s^{-1}. The chance of detecting appreciable H I absorption is greatest in the most compact radio sources, GPSs and CSOs, where it can occur in circumnuclear "disks" or "tori", as well as in gas enveloping jets and hot spots; inferred densities range at least between 10 cm^{-3} and 10^4 cm^{-3}. But H I absorption occurs also in some CSSs, perhaps associated with jet-cloud interaction regions, and in quasars with a large optical reddening. VLBI observations at the unusual UHF frequencies of redshifted H I 21 cm can give unique "sight"lines into the physics and evolution of young radio sources and their inner galactic medium.

1. Introduction

Until recently, the galactic medium at cosmological redshifts was largely unexplored, but after the advent at the WSRT of wideband UHF receivers, spanning 700–1200 MHz, systematic surveys for H I 21 cm line absorption associated with radio-loud active galaxies in the redshift range $z = 0.2$ to $z = 1.0$ have been done by different collaborations and with a variety of goals. The emphasis has been on bright, compact radio sources, which were a priori thought to be likely targets for successful detections, with the potential to use the lines to draw astrophysically interesting conclusions. Indeed, in the early H I 21 cm absorption line search of galaxies at relatively low redshifts by van Gorkom et al. (1989), the 4 detections (out of 29 objects observed) were all in CSOs or sources with similarly compact structure. Absorption was detected at the WSRT in 27/84 targets analysed to date; highlights and trends will be discussed here.

2. CSOs

Compact Symmetric Objects (CSOs) are defined as having radio lobes visible on both sides of the central engine but not extending over more than 1 kpc (Wilkinson et al. 1994). Many CSOs have an overall Gigahertz-Peaked Spectrum (GPS); others are amongst the smallest Compact Steep-Spectrum souces (CSSs).

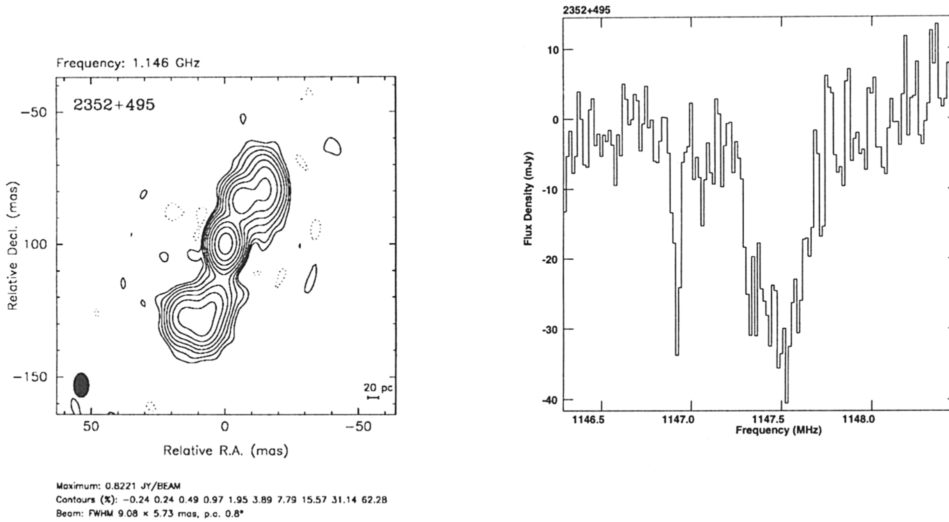

Figure 1. Observations at 1147 MHz (H I at $z = 0.24$) of the CSO 2352+495. Left: continuum VLBI image. Right: Spectrum of the central component, which shows absorption.

The CSS class also contains Medium-size Symmetric Objects (MSOs, Fanti et al. 1995), ranging in size up to 15 kpc. A recent review was given by O'Dea (1998).

It is now commonly thought that CSOs and MSOs are the early stages of an evolutionary sequence ending up at powerful extended radio sources. Back-extrapolated hotspot advance speeds imply total radio source ages of less than 1000 years in several CSOs (Owsianik & Conway 1998; Owsianik, Conway, & Polatidis 1998; Owsianik, Conway, & Polatidis 1999). MSOs are thought to have ages ranging between 10^4 and 10^5 years (Fanti et al. 1995). However, while the enveloping media probably do not permanently "frustrate" the radio sources in their growth, jet-cloud or more generally jet-envelope interactions in the narrow line region of the inner galaxy could well be dynamically important.

With the WSRT, 6/7 CSOs in the complete PR sample (Pearson & Readhead 1988) were surveyed for H I absorption (0710+439 had excessive external interference). This yielded 4/6 detections (Vermeulen et al. in preparation); peak optical depths and limits are: 0108+388, 44%; 0404+768, 2.5%; 1031+567, <1%; 1358+624, 0.4%; 2021+614, <0.2%; 2352+495, 1.5% (shown in Figure 1 as a representative example). Some of the line profiles can be reasonably approximated by a single Gaussian, but others have a rather more complex structure; the velocity widths range from 10 km s^{-1} to 300 km s^{-1}. In fainter CSOs similar absorption lines have been detected for 5/10 sources (Tschager et al. in preparation) in the CJF sample (Taylor et al. 1996a) and 1/2 additional sources in the COINS sample (Peck et al. 2000), but a comparison with the brighter PR CSOs is not yet meaningful since detection limits $\leq$1% were not always reached.

Preliminary analysis of a VLBI observation at 1147 MHz (H I at $z = 0.24$) suggests that the absorption in 2352+495 may be confined to the central part of

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the continuum structure (shown in Figure 1), $\leq$50 pc across (Vermeulen et al. in preparation). The absorption line profile is then likely to be probing a toroidal or disk-like region around the active nucleus, and perpendicular to the inner jets. Disks or tori with a thickness of only a few pc have been demonstrated to cover a portion of the receding jet in the lower redshift galaxies Cygnus A (Conway & Blanco 1995, Conway 1999) and NGC 4261 (van Langevelde et al. 1999). But in the radio galaxy Hydra A (Taylor 1996), and in the low-redshift CSO 4C31.04 (Conway 1996), a geometrically thick disk, extending over several tens of pc, covers part of the approaching jet as well. It seems that a thick disk/torus scenario might apply to 2352+495: the central radio component in Figure 1 is probably almost entirely from the approaching (Doppler boosted ?) jet, because the true core is not visible due to synchrotron self-absorption, free-free absorption, or both (see Taylor, Readhead, & Pearson 1996b).

Maloney (1999) has argued that circumnuclear tori or disks could be in a largely atomic state at $T \sim 8000$ K; adopting this as the spin temperature yields a column density of $N(\mathrm{H}) \gtrsim 10^{21}$ cm^{-2} for the narrowest absorption feature in 2352+495, and $N(\mathrm{H}) \sim 10^{24}$ cm^{-2} for the deep absorption in 0108+388. Subject to substantial uncertainty in the actual size and geometry of the covering region, the absorbers have particle densities of $n(\mathrm{H}) \geq 10^2$ cm^{-3} for the narrow absorber in 2352+495 to $n(\mathrm{H}) \geq 10^4$ cm^{-3} for 0108+388.

However, in another PR CSO, 0404+768, preliminary VLBI observations at 886 MHz (H I at $z = 0.60$) indicate that the total flux density of the central region is insufficient for the main absorption line. It probably arises against part or all of the outer lobes, which together extend over almost 1 kpc (Vermeulen et al. in preparation). The inferred atomic gas density is $n(\mathrm{H}) \geq 10$ cm^{-3} (limited by assuming uniform coverage). Detailed VLBI observations may be able to probe in a cosmologically distant galaxy the properties of an atomic gas disk, which could be analoguous to those found through H I absorption in nearby Seyfert galaxies by Gallimore et al. (1999). But in addition, VLBI spectral imaging will also reveal whether and how the radio jets and lobes in young powerful radio sources interact with their gaseous environment (for which Seyfert galaxies like IC 5063 might be low-redshift analogues; see Oosterloo et al. 2000).

3. CSSs

The recent WSRT suveys show a definite but by no means exclusive trend of diminishing H I absorption with increasing linear extent of the radio sources (Pihlström et al. in preparation); this was already suspected by Conway (1996). The larger sources are well outside the torus and accretion disk area, and probably probe regions with a lower atomic gas column density.

The shallowest absorption line detected to date, in the CSS galaxy 3C213.1, has only 0.1% peak depth, but in 3C49 (3.6%) and 3C268.3 (12%) prominent absorption exists (de Vries et al. in preparation). In both of these, (part of) one of the radio lobes is coincident, at least in projection, with an optically prominent feature or knot in the host galaxy. If VLBI observations confirm that the optical knots are the sites of the H I absorption, this offers unique opportunities to study the "alignment effect" and details of jet-cloud interactions in cosmologically distant sources. A jet-cloud interaction site is also the most plausible location of the H I absorption found in the "superluminal CSS" quasar 3C216, where, because of its orientation, the circumnuclear disk or torus is unlikely to be visible in absorption (Pihlström et al. 1999).

4. Quasars

Normal core-dominated quasars are unlikely to show H I absorption (Pihlström et al. in preparation), but 2/3 non-CSS quasars pre-selected to have high optical reddening (from Stickel et al. 1996) were found to have significant H I absorption (probably associated, intervening systems are not dealt with here): 0500+019, 3.6%; 1504+377, 34%; 2149+056, <1.5% (Carilli et al. 1998).

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